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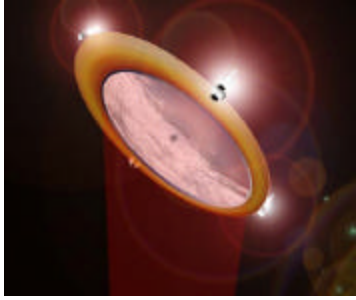
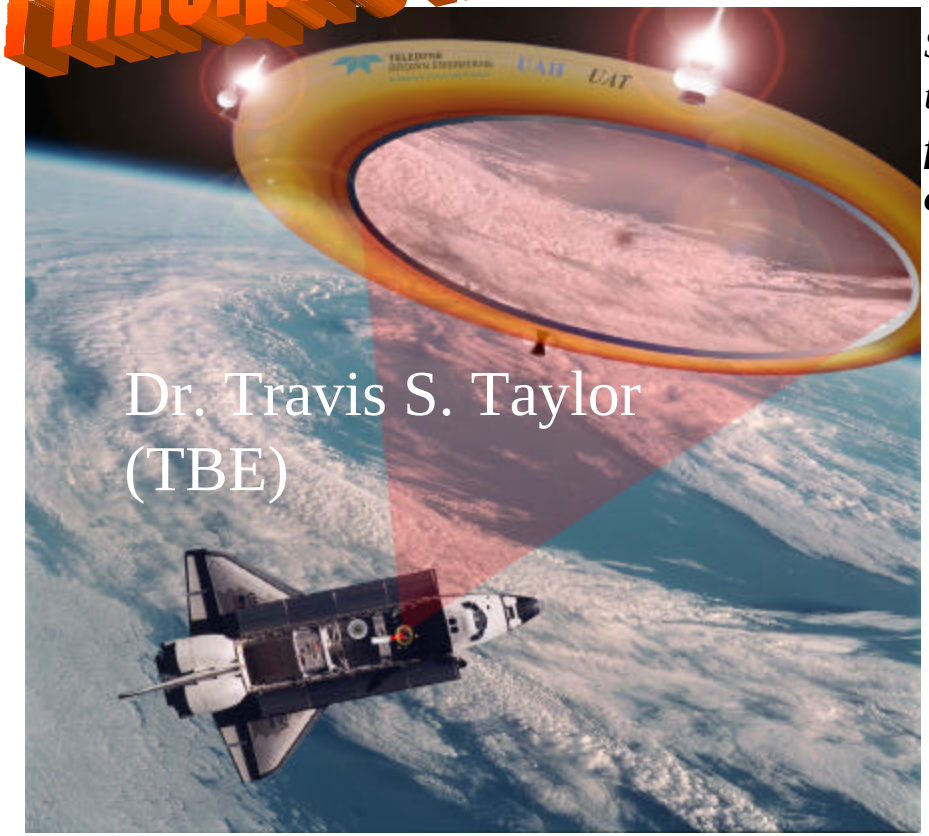


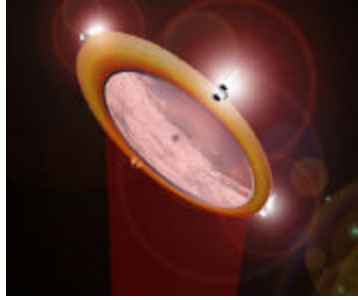
Light Sail Systems Engineering Concepts for Outer Planet Probes

Principle Investigator:



Studies have been conducted which demonstrate the technical feasibility of solar sailing. ***However, for all of these sometimes heroic efforts an operational solar sail has yet to fly****.*

Colin R. McInnes
from *Solar Sailing Technology, Dynamics, and Mission Applications*



Light Sail Systems Engineering Concepts for Outer Planet Probes

- **What is known and what has typically been done**
  - Interplanetary space travel can be made possible with the use of solar and laser sailing vessels.
  - The idea of solar/laser sailing is not new.
  - Most text omit a concise technical description of the large scale components.
  - Minimal optical and structural analysis of the sail has been performed.
  - Minimal systems engineering has been performed.

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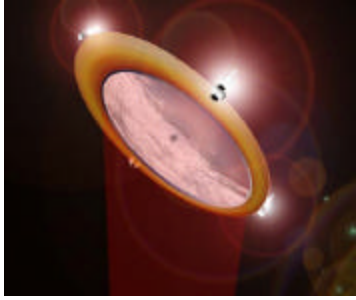

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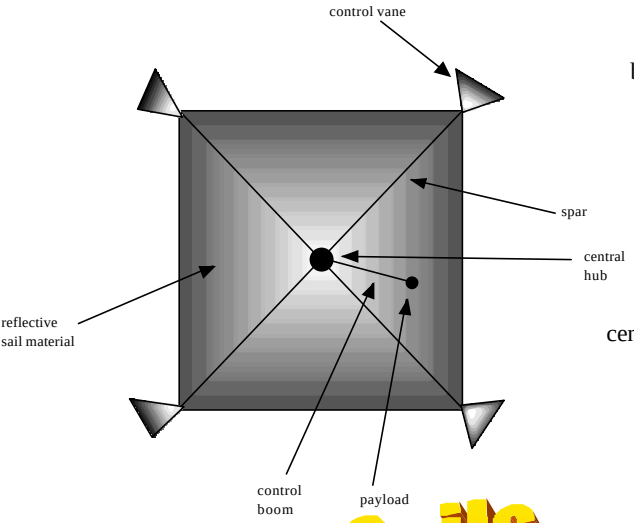
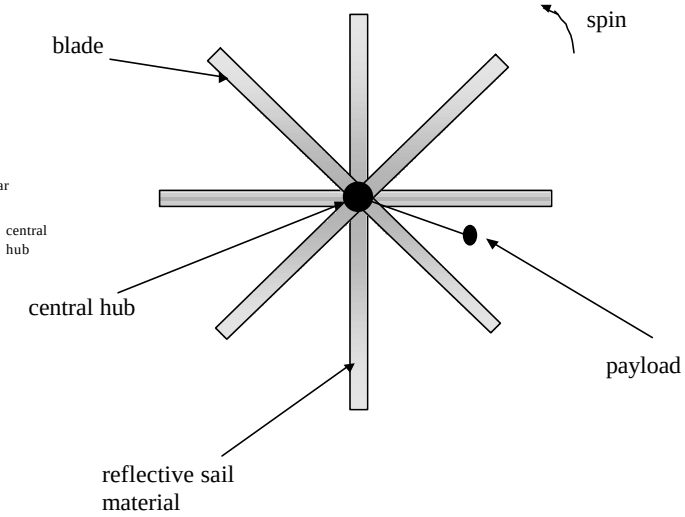
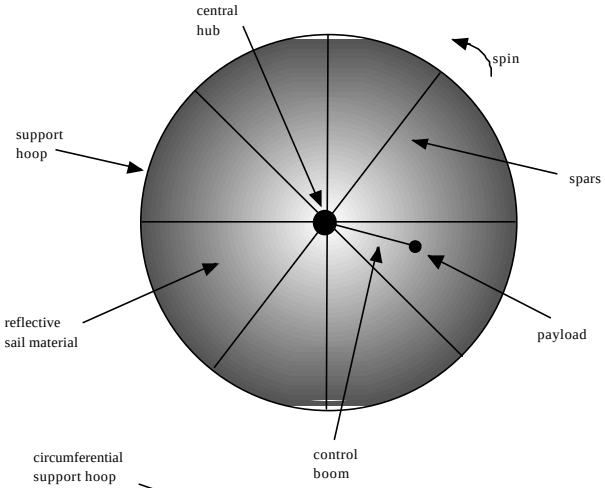
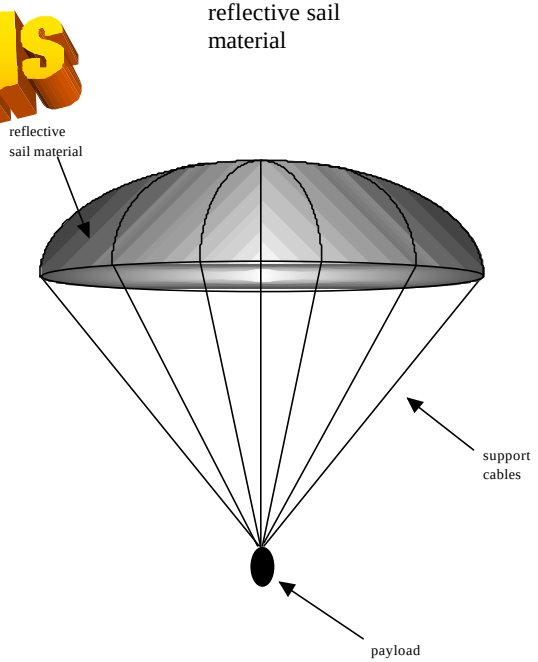
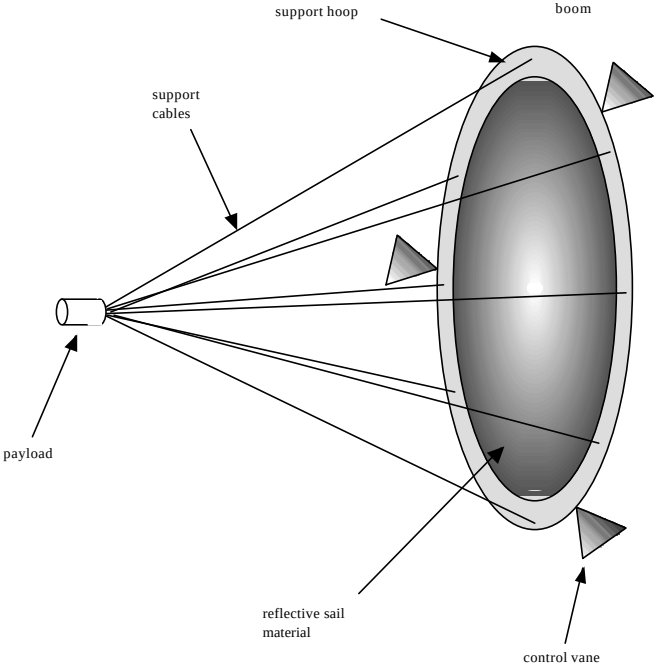






Types of Sails





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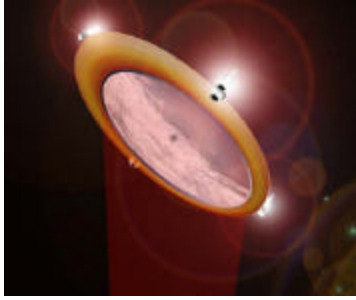

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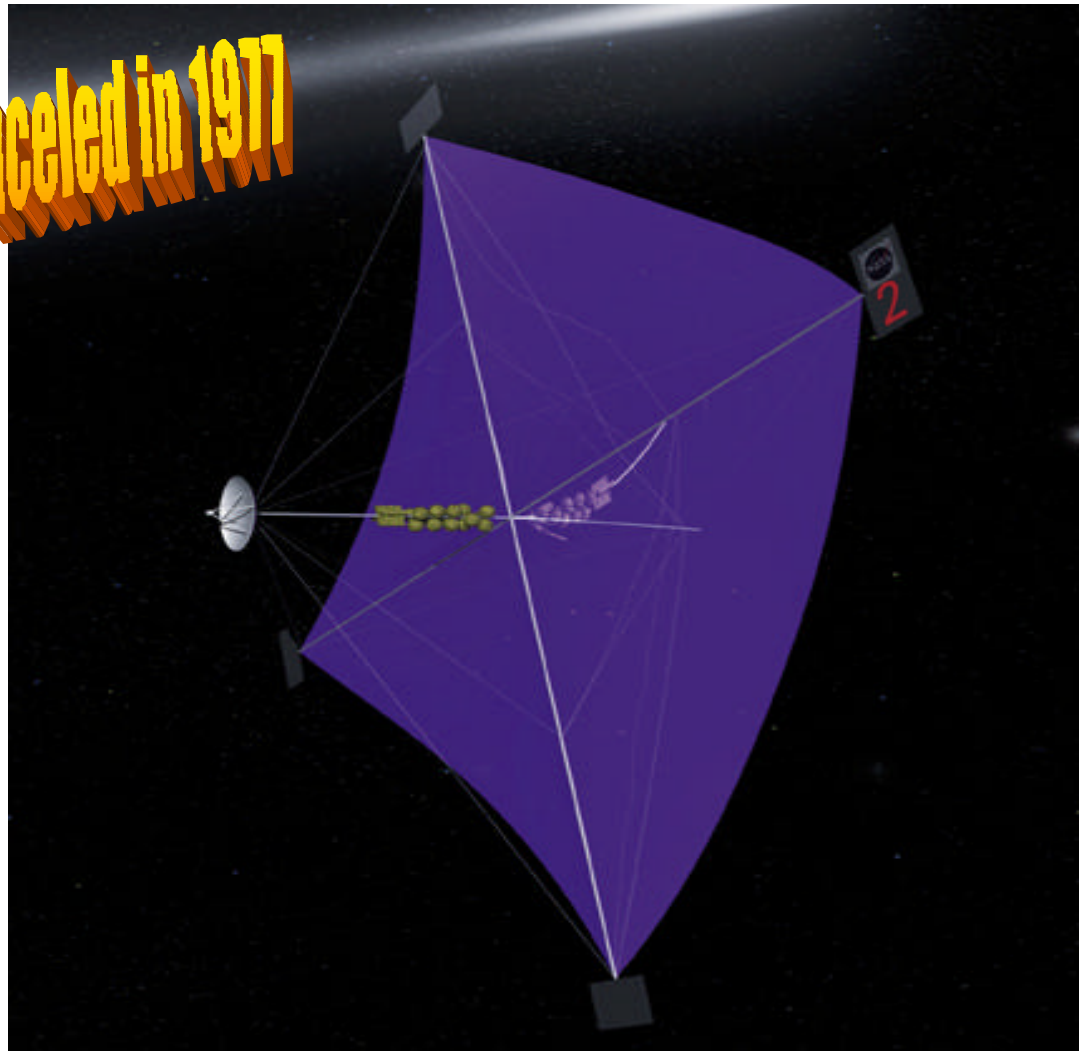
Comet Halley Rendezvous: canceled in 1977



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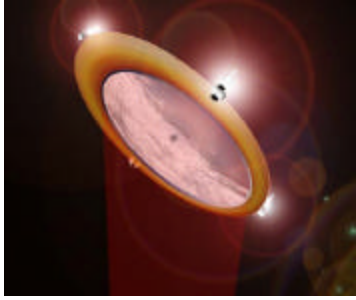
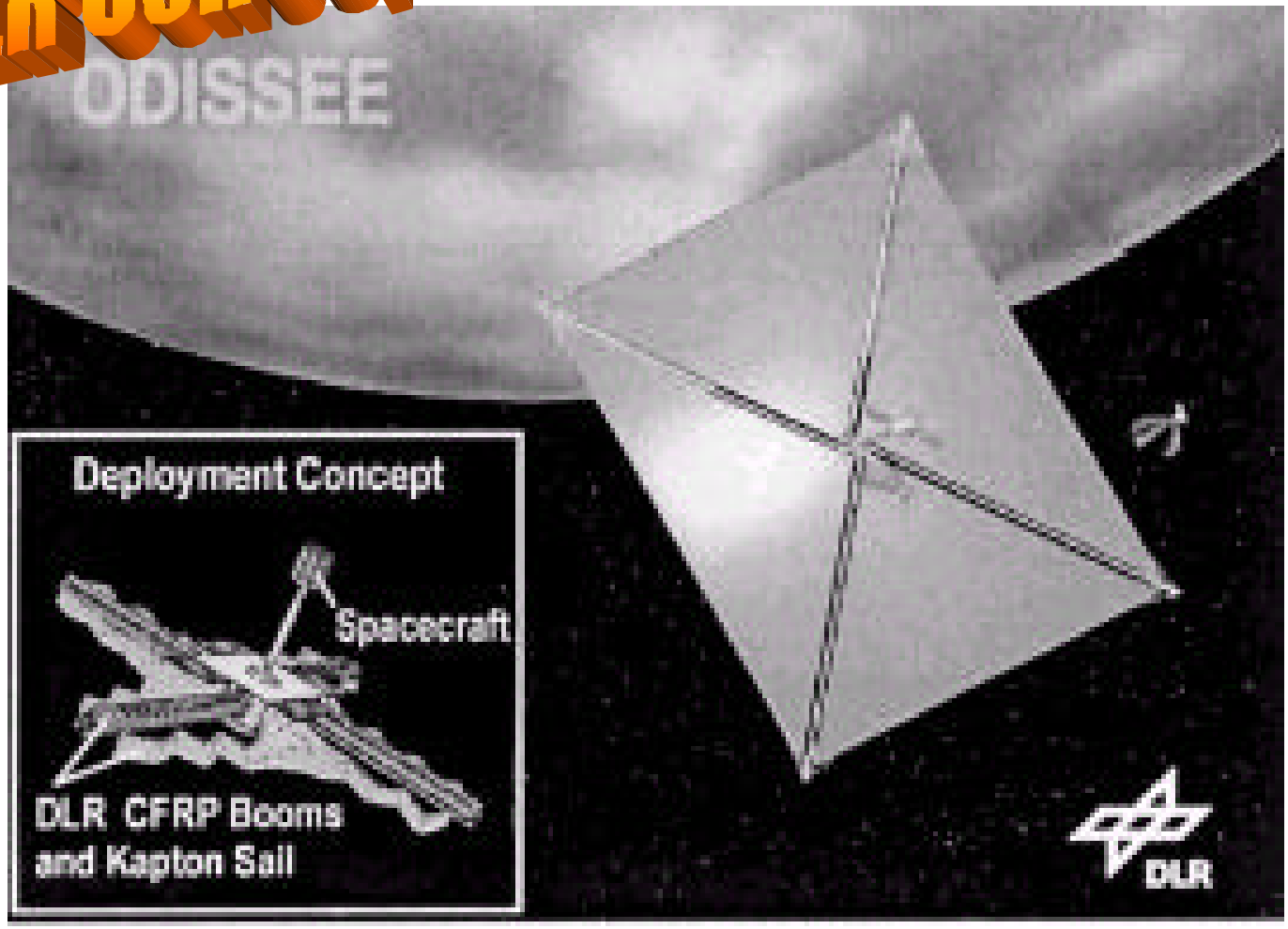
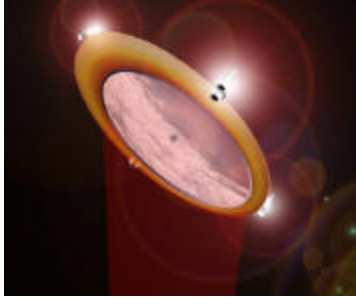


Light Sail Systems Engineering Concepts for Outer Planet Probes

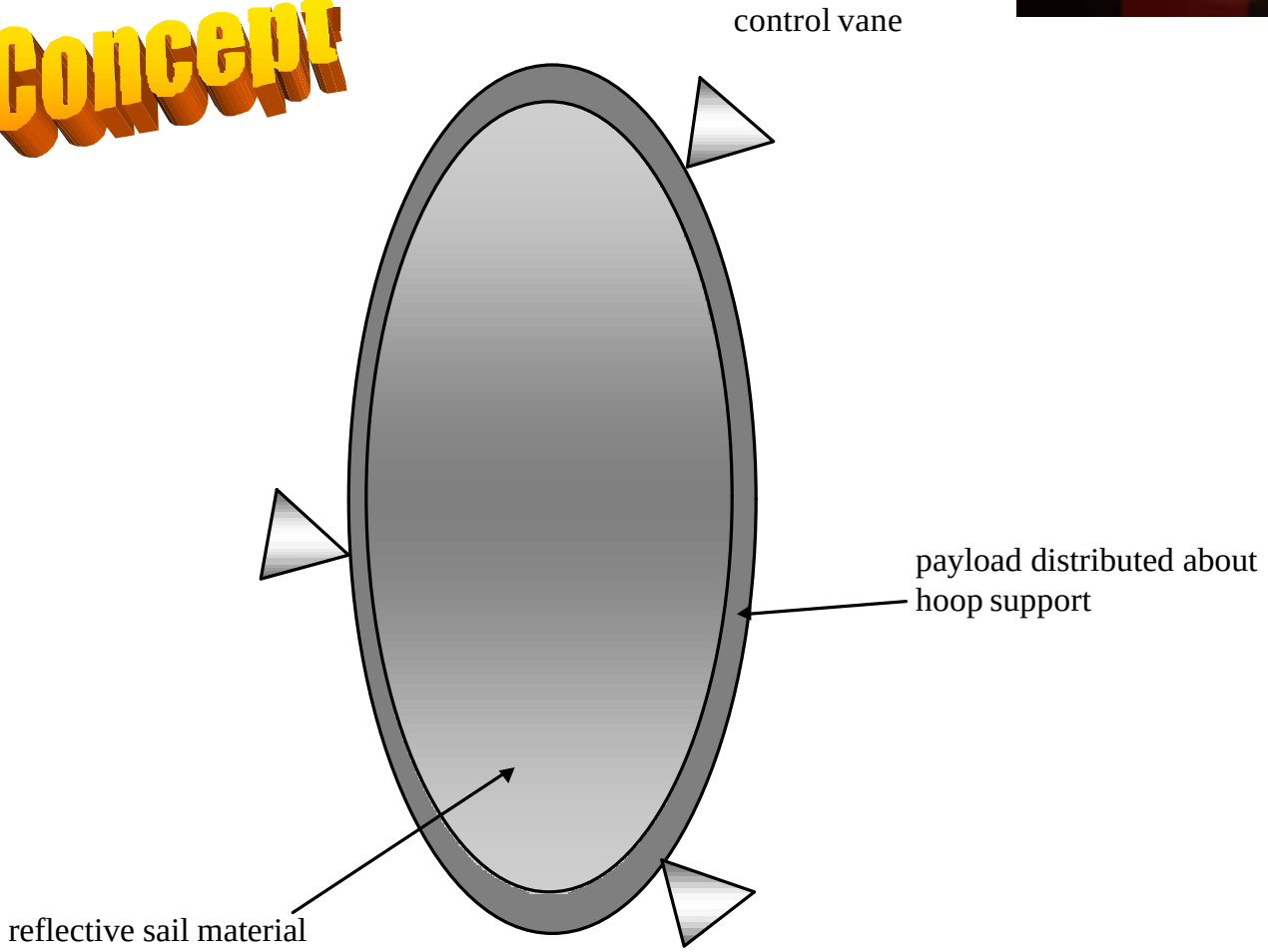
JPL/DLR Concepts





Light Sail Systems Engineering Concepts for Outer Planet Probes

TBE Baseline Concept



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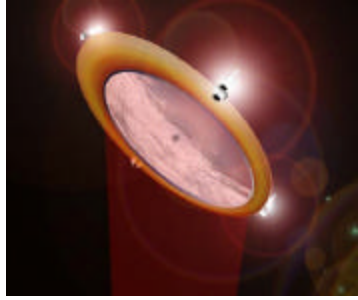
DLR/JPL Approach is 23 years old!



Light S[illegible]ineering Concepts for Outer Planet Probes

DLR/JPL

40x40 m sail demonstrator:

Boom ~ 5.6 kg

Sail ~ 4.4 kg

$$m_{boom} > m_{sail}$$

$$m_{boom} = 2\sigma_{boom}\sqrt{L^2 + L^2}$$

$$m_{sail} = \sigma_{sail} L^2$$

$$\frac{m_{boom}}{m_{sail}} = 1.27$$

TBE/UAH/UAT Inc./MSFC

22.57 m radius sail demonstrator:

Boom ~ 0.89 kg

Sail ~ 4.8 kg

$$m_{boom} < m_{sail}\text{!!!}$$

$$m_{boom} = 4\pi^2 R_{torus} R_{sail} \sigma_{boom}$$

$$m_{sail} = \sigma_{sail} \pi R^2$$

$$\frac{m_{boom}}{m_{sail}} = 0.158$$

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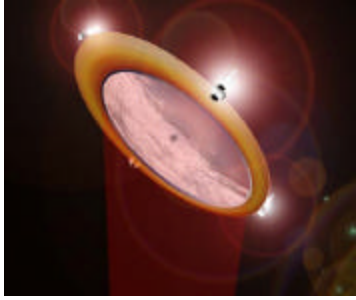
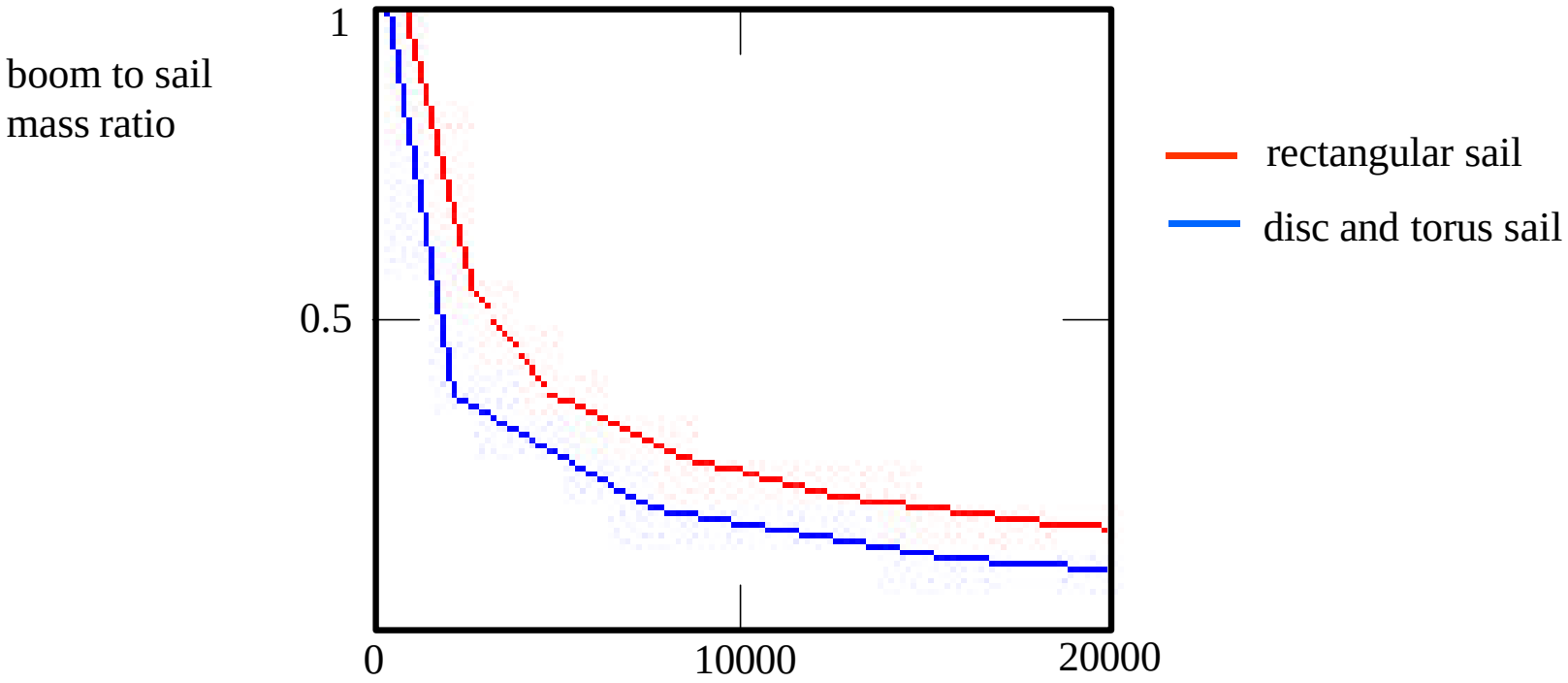


Light Sail Systems Engineering Concepts for Outer Planet Probes



Light Sail S[illegible]pts for Outer Planet Probes

Other Advantages of TBE Sail Architecture

- no deployment structures needed (stored energy self deployment)
- no deployment mechanisms needed
- no billowing sail dynamics due to preformed structure
- convex surface allows for stable dynamics
- concave outgoing side can be used as sensor (with booms and focal plane detector added)

0.5 m diameter mirrors, support, and detector assembly

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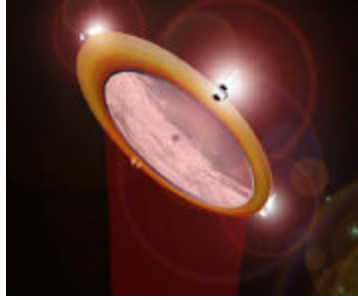
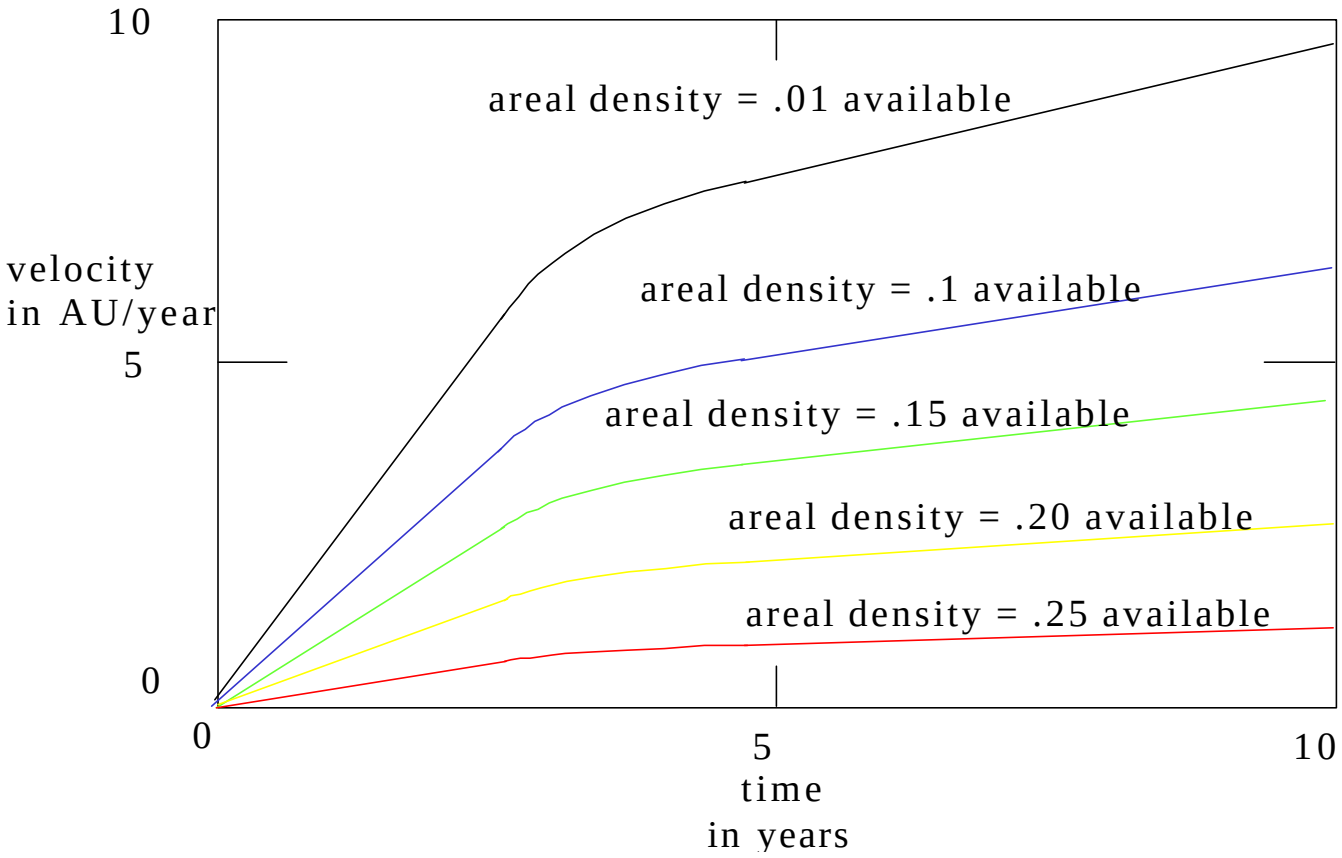


Light Sail Systems Engineering Concepts for Outer Planet Probes

Assuming current Polyimides of ~4 g/m^2, 100 kg payload, and 500 m diameter sail



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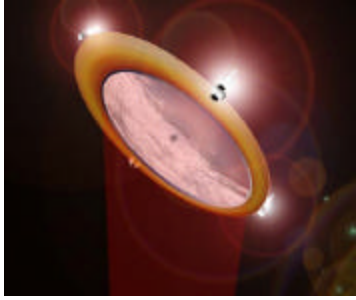
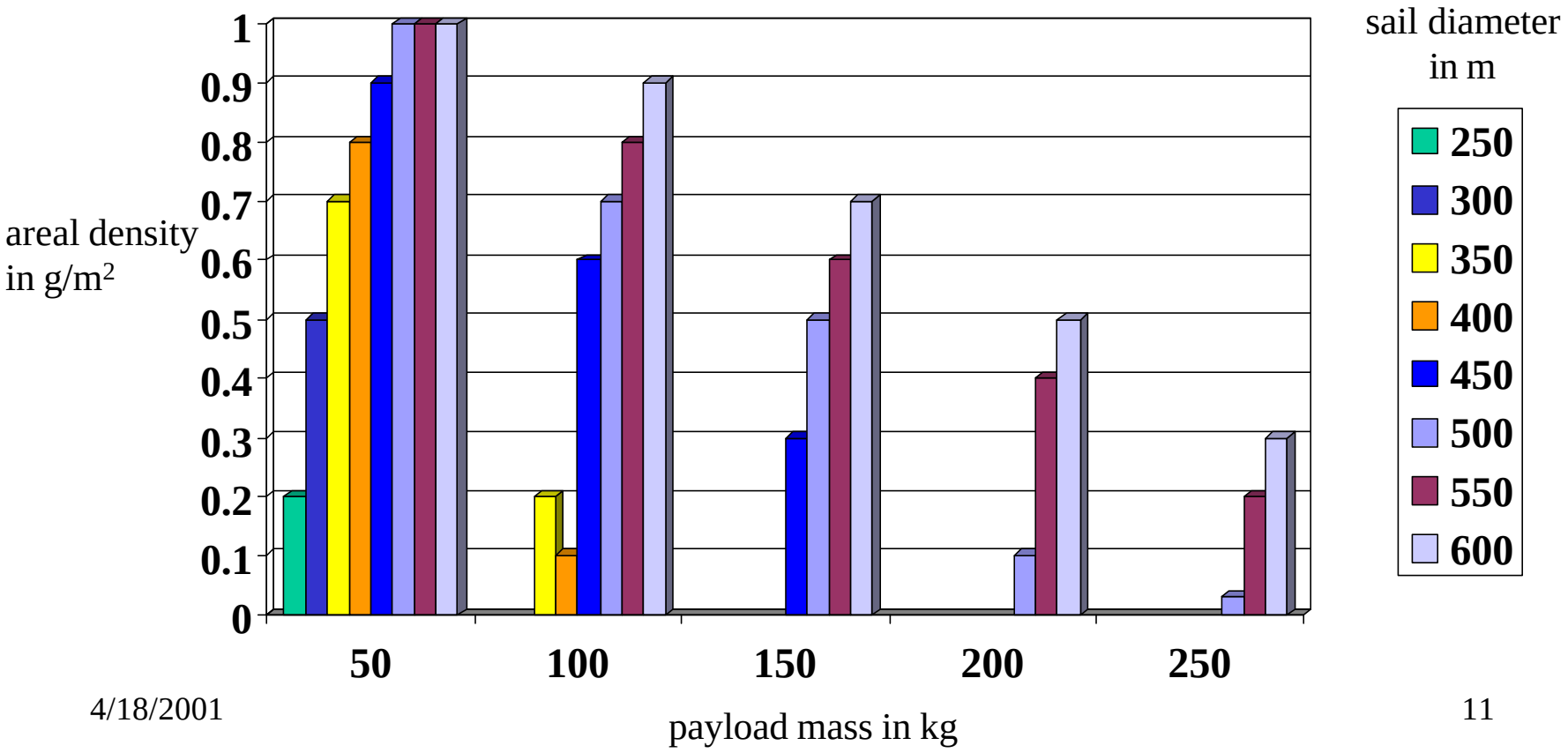


Light Sail Systems Engineering Concepts for Outer Planet Probes

Areal Density Required for 10 Year Pluto Flyby



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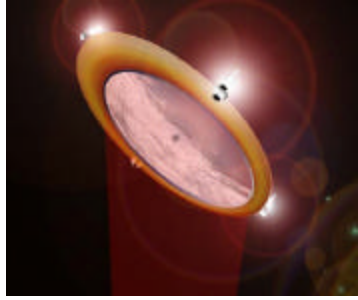
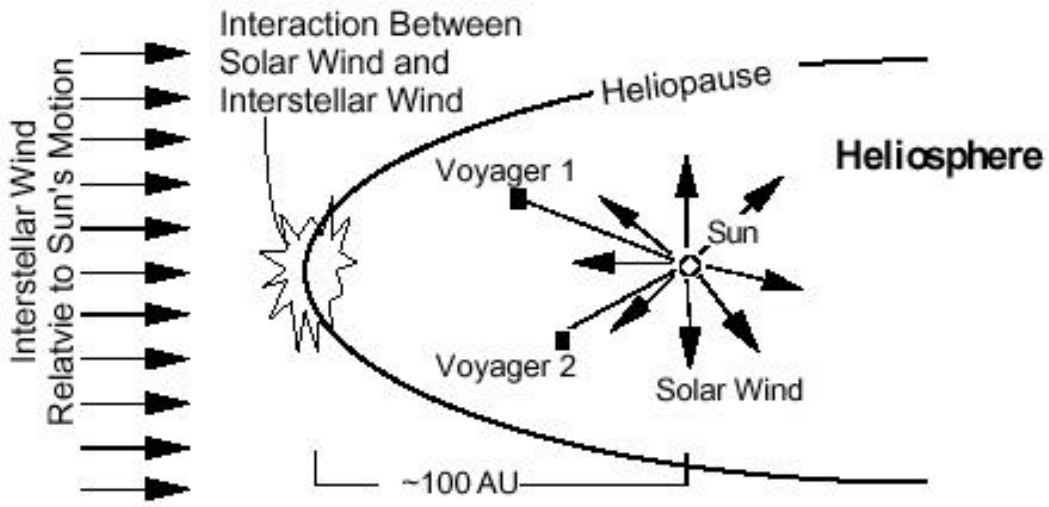


Light Sail Systems Engineering Concepts for Outer Planet Probes

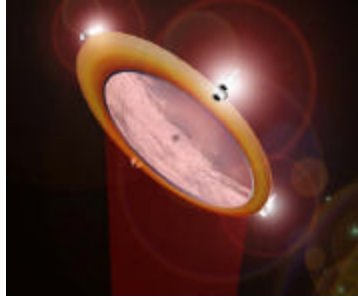
25 Year Heliopause Mission Possible!

@ 4 AU/year



Basics of Spaceflight Learner's Workbook

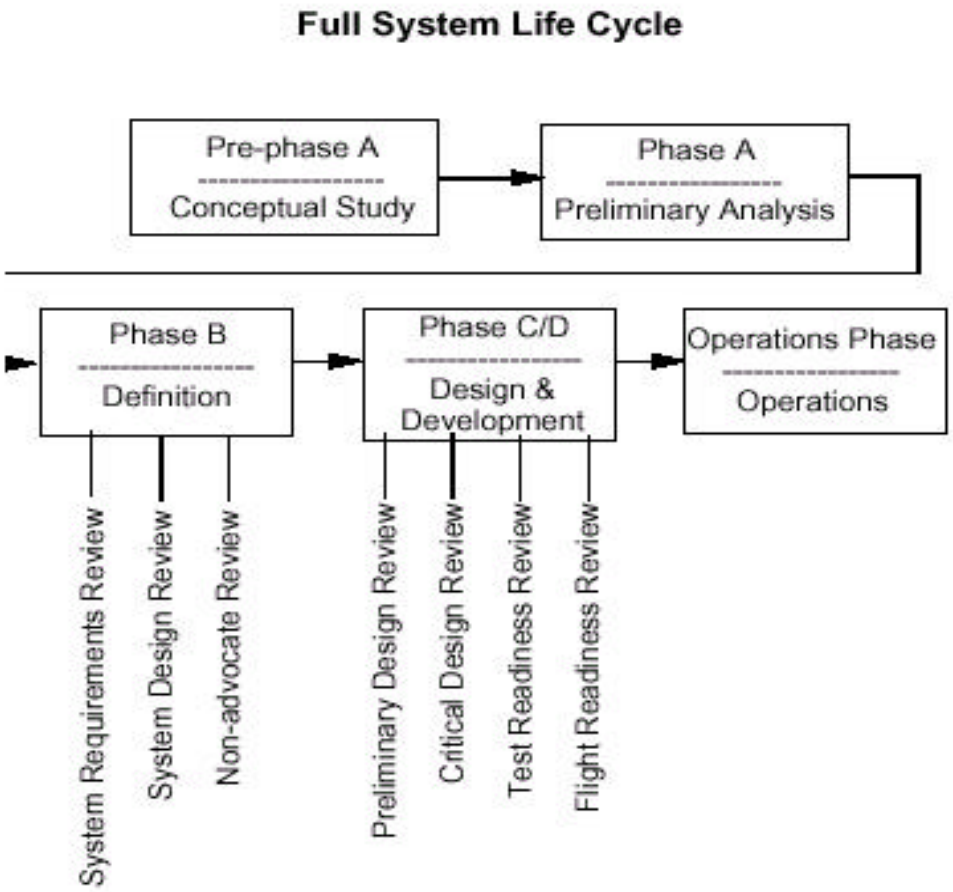
D. Doody, G. Stephan, 1995



Light Sail Systems Engineering Concepts for Outer Planet Probes

Current status of solar sailing is between Phase A and Phase B!

Could be moved ahead at a rapid pace. Many scientists and engineers are ready for the task.



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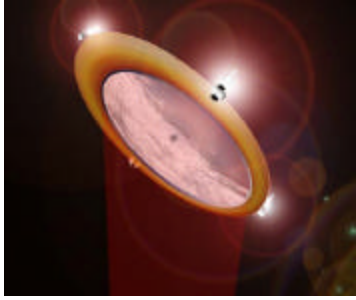
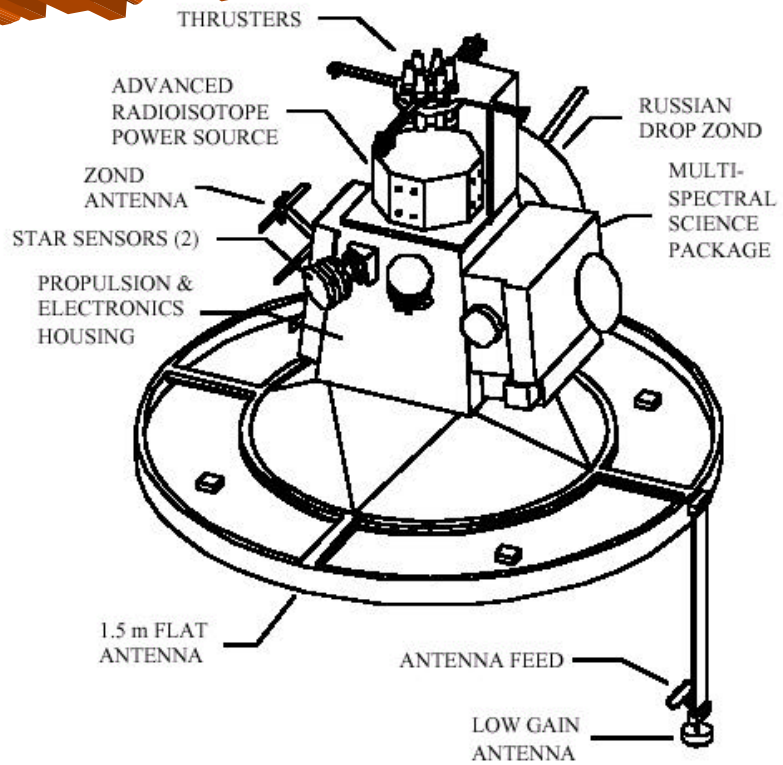


Light Sail Systems Engineering Concepts for Outer Planet Probes

JPL proposed Pluto Spacecraft



Classification: Flyby spacecraft

Mission: Conduct the first reconnaissance of Pluto

Features: Two low-mass spacecraft are being considered for separate launches on fast, direct trajectories to reach the Pluto-Charon system in 6 to 8 years. Science objectives established by NASA's Outer Planets Science Working Group and the Solar System Exploration Subcommittee

Science: global geology and geomorphology, and mapping the surface composition of both bodies, and characterize the tenuous atmosphere.

Instrument Package: imaging camera, and UV and IR spectrometers.

Payload Mass: **mass ~ 150 kg** including propellant.

Stabilization: Three-axis stabilized by thrusters.

Basics of Spaceflight Learner's Workbook

D. Doody, G. Stephan, 1995

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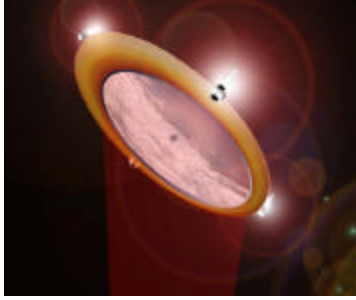


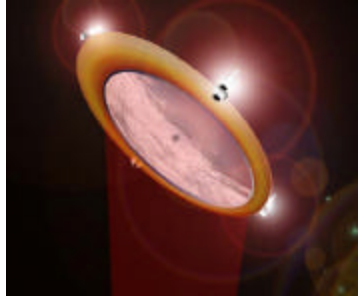
Light Sail Systems Engineering Concepts for Outer Planet Probes

Preliminary Research

- Theory and Analysis
  - sail design
  - thermal analysis
  - optical analysis
  - structural integrity analysis
  - packaging theory
  - deployment theory and design
  - guidance theory
  - orbit transfer theory
  - orbit based laser design and analysis
  - laser sail theory

Future Effort

- Experiment and Construction
  - vacuum tests on sail material
  - sail construction methodology
  - construct sail and payload
  - package sail and payload
  - test deployment
  - package and test deployment in orbit
  - test guidance and control
  - transfer orbit to lunar rendezvous
  - illuminate sail with earth based laser
  - illuminate sail with space based laser



Light Sail Systems Engineering Concepts for Outer Planet Probes

Summary and Conclusions

- Hybrid lightsail spacecraft analysis should be conducted at more serious level
- Systems engineering of large sailcraft has begun.
- An ***UPDATED*** spacecraft baseline design has been achieved at half the mass of current considered systems!!!
- This research suggests that a probe could reach Pluto in about 10 years and the Heliopause in 25 years!